

# Food fortification: A tool for fighting hidden hunger

Alberto Nilson and Jaime Piza

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## Abstract

*This paper reviews the fortification of staple food as a tool to prevent micronutrient deficiencies. The rationale for fortifying salt, wheat flour, milk, and margarine was developed in the 1920s and 1940s, mainly in industrialized countries. At that time, fortification of staple foods was considered by only a few developing countries. Recent research has shown that the prevalences of some deficiencies (clinical and marginal) in some developing countries are higher than expected. Even more important has been the realization that the impact of marginal deficiencies on health and socio-economic development is considerably more important than the impact of clinical deficiencies. Iron, vitamin A, and iodine have gained more attention, but deficiencies of other micronutrients are also relevant. This paper shows that fortification of staple foods to prevent micronutrient deficiencies is effective, easy, fast, safe, and relatively inexpensive.*

## Introduction

The scientific rationale, including technology, stability, interactions, and effectiveness, for fortifying staple foods was developed early this century. In the 1920s and 1940s fortification of salt with iodine, fortification of wheat flour with iron, vitamins B<sub>1</sub> and B<sub>2</sub>, and niacin, fortification of milk with vitamins A and D, and fortification of margarine with vitamins A and D were fully evaluated and included as part of national intervention programmes in several countries. For whatever reason, these strategies were adopted only by some developed countries.

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Alberto Nilson is based in São Paulo, Brazil, and is Director of the Regional Center for Latin America of the Vitamin Division of F. Hoffmann-La Roche Ltd., Basel, Switzerland. Jaime Piza is based in San José, Costa Rica, and is Manager for Central America and the Caribbean of the Vitamin Division of F. Hoffmann-La Roche.

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In the following decades, developing countries gave their attention mainly to clinical deficiencies, using the medical approach of supplementing the population at highest risk as soon as symptoms appeared. The most challenging problems have been xerophthalmia, anaemia, and goitre. Consequently, attention to other micronutrients has been practically nil.

Later research has shown that marginal deficiency is even more important than clinical deficiency, as it covers larger percentages of the population. Evidence has been accumulating showing the enormous impact of marginal deficiencies of vitamin A on infant and maternal mortality and morbidity, of iron on IQ in children and working capacity in the whole population, and of folic acid on neural tube defects.

Furthermore, there is growing evidence that micronutrients interact positively with each other. For example, vitamin C improves the absorption of non-haem iron from foods or supplements, and vitamin A together with supplementary iron is more effective than iron alone in reducing the prevalence of iron deficiency.

Although not the objective of this paper, it is worth mentioning that an adequate intake of some micronutrients, mainly vitamins E and C, sometimes at levels higher than the established recommended dietary allowances (RDAs), may play an important role in reducing the prevalence of cancer, cardiovascular diseases, and other health problems.

The above facts and the cost of potential intervention programmes show that the cost-benefit ratio of such programmes is highly favourable, motivating the scientific community, international agencies, and governments to seek alternatives for preventing micronutrient deficiencies through supplementation, fortification, and dietary diversification.

Staple foods such as wheat flour, milk, and margarine traditionally have been considered for fortification. Recent research has looked at alternative vehicles for one or more micronutrients, such as rice, oils, tea, maize, weaning foods, beverages, and foods for complementary feeding programmes [1].

Some more recent successful examples of efforts to

prevent deficiencies include fortification of sugar with vitamin A in Central America, fortification of pre-cooked corn flour with vitamins A, B<sub>1</sub> and B<sub>2</sub>, and niacin and iron in Venezuela, and fortification of a milk substitute and biscuits with several micronutrients as part of the complementary feeding programmes in Peru.

It is also worth mentioning the fortification efforts of the food industry. Some examples are the fortification of milk with iron in Argentina and Brazil, fortification of noodles with iron and vitamin A in Thailand and the Philippines, and fortification of chocolate powder for milk with iron and several vitamins in Mexico.

## Micronutrient deficiencies

Micronutrient malnutrition is a widespread problem throughout the world that has both health and economic consequences. The latest estimates show that 254 million children suffer from clinical and marginal vitamin A deficiency [2], 2.2 billion people, mainly children and pregnant women, suffer from iron deficiency [3], and 1 billion suffer from iodine deficiency [4].

Furthermore, there is some evidence that the prevalence of other micronutrient deficiencies could be much higher than expected. Table 1 shows a recent compilation, by Dr. José Mora, of the evidence available on micronutrient deficiencies in Latin America, confirming the high prevalence of vitamin A, iron, and iodine deficiencies. Despite the lack of information on other micronutrients, there is enough information to suggest that there could be a regional problem, at least for

some groups or in some regions, for vitamin B<sub>2</sub>, niacin, folic acid, calcium, zinc, and even vitamin C. If a micronutrient is not mentioned in table 1, it is not necessarily because there is no problem, but rather that there is a lack of information.

## Global commitment

In 1990, at the World Summit for Children, WHO, UNICEF, and the US Agency for International Development set specific micronutrient goals for the year 2000. These goals were unanimously confirmed by 159 countries at the International Conference on Nutrition held in December 1992 in Rome [5], and a plan of action was adopted. These objectives are to:

- » virtually eliminate vitamin A deficiency;
- » virtually eliminate iodine deficiency;
- » reduce iron-deficiency anaemia by one-third of the 1990 levels;
- » pay attention to other micronutrient deficiencies, such as B-complex vitamins, vitamin C, zinc, and calcium.

Three approaches are currently being implemented to address micronutrient deficiencies: food fortification, food supplementation, and dietary diversification. An intervention programme must consider a mix of these approaches.

## Fortification

The results of fortification are fast, broad, and sustain-

TABLE 1. Evidence of micronutrient deficiencies in Latin America

Country	National deficiency	Deficiency in certain areas	Deficiency in certain groups	Widespread low intake
Argentina	Fe	I	Fe	Vitamins A, C, E
Bolivia	Fe	I, vitamin C	Vitamin A	Ca, vitamins B <sub>1</sub> , B <sub>2</sub> , niacin
Brazil	Fe	I, vitamin A	Vitamin A	Vitamins B <sub>2</sub> , E
Chile			Fe	Ca, vitamins B <sub>1</sub> , B <sub>2</sub> , B <sub>6</sub> , C
Colombia	Fe	I		Vitamins A, B <sub>1</sub> , B <sub>2</sub> , niacin
Costa Rica		I		
Dominican Republic	Fe, vitamin A, folate	I		
Ecuador	Fe, vitamins A, B <sub>2</sub> , niacin	Zn	Zn	
El Salvador	Fe, vitamin A, I			
Guatemala	Fe, vitamin A	I		
Honduras	Fe, vitamin A	I		
Mexico	Fe, vitamin B <sub>2</sub>	I, Ca, niacin	Vitamin C, folate	Vitamins A, B <sub>1</sub> , B <sub>2</sub> , C, niacin, Zn
Nicaragua	Fe, vitamin A	I		Vitamin B <sub>1</sub> , niacin
Panama	Fe	I	Vitamin A	
Peru	Fe, I	Vitamin A	Folate, vitamin B <sub>12</sub> , Zn	Ca, vitamins B <sub>1</sub> , B <sub>2</sub>

able. The nutrient intakes of the targeted group improve immediately, and an impact on micronutrient status can be detected within one to three months. When a staple food that is consumed regularly by the majority of the population is used as a fortification vehicle, high population coverage can be easily achieved.

#### Fortification vehicles

To ensure that the most vulnerable members of the population benefit from food fortification, the food vehicle(s) must be staple food(s) consumed throughout the year by a large proportion of the population at risk. In order to reach different segments of the population who have different diets, it may be more effective to select more than one food vehicle.

When selecting a staple food as a suitable vehicle for compulsory fortification with micronutrients, the following generally accepted criteria must be met [6]:

- » The food selected as a vehicle should be consumed by the population at risk.
- » The intake of the food should be stable and uniform; the upper and lower levels of intake should be known.
- » The essential nutrient(s) should be present in amounts that are neither excessive nor insignificant, taking into account intakes from other dietary sources.
- » The amount of essential nutrient(s) should be sufficient to correct or prevent the deficiency when the food is consumed in normal amounts by the population at risk.
- » The nutrient(s) added should not adversely affect the metabolism of any other nutrients.
- » The nutrient(s) added should be sufficiently stable in the food under customary conditions of packing, storage, distribution, and use.
- » The nutrient(s) added should be physiologically available from the food.
- » The nutrient(s) added should not impart undesirable characteristics to the food (changes in colour, taste, smell, texture, or cooking properties) and should not unduly shorten the shelf life.
- » The technology and processing facilities should be available to permit addition of the nutrient(s) in a satisfactory manner.

- » The additional cost to the consumer resulting from the fortification should be reasonable.
- » Methods of measuring, controlling, and enforcing the levels of the essential nutrient(s) added to food should be available.

#### Fortification of staple food: A successful history

In 1923 Switzerland was the first country to fortify salt with iodine to prevent goitre and cretinism, which were widespread throughout the Alpine region. The initiative was later followed by the United States in 1930 [6].

Rickets, caused by vitamin D deficiency, was once common in young children in the northern hemisphere because of the lack of sunshine in the winter months and the low consumption of this vitamin. In 1923 the United Kingdom and the United States started fortifying milk with vitamin D to prevent rickets [6].

Margarine was the first substitute or imitation food produced on a large industrial scale. Its introduction in Denmark in 1910 led to widespread clinical deficiency of vitamin A in children (xerophthalmia). It was soon recognized that to be nutritionally equivalent to butter, margarine had to be fortified with vitamin A, eliminating xerophthalmia in Denmark. Vitamin D was added later [7].

Before 1933 the population of Newfoundland suffered from multiple nutrient deficiencies. The government, aware of the micronutrient losses during wheat milling, banned the consumption of white wheat flour in order to preserve the nutritional value of wheat. However, the population did not like to consume whole-wheat flour, and the programme failed to achieve the expected results. In 1944 the government started fortifying white wheat flour with vitamins B<sub>1</sub> and B<sub>2</sub>, niacin, and iron and fortifying margarine with vitamin A. The results were remarkable. Various clinical symptoms and indications of vitamins A and B deficiencies, such as skin follicular changes, eye hyperaemia, and magenta tongue, were substantially reduced or eliminated. Beriberi was eliminated completely (fig. 1), and infant mortality in the first year of life fell from 102/1,000 live births in 1944 to 61 in 1947. The biochemical indicators of deficiency of vitamins A, B<sub>1</sub>, and B<sub>2</sub> improved

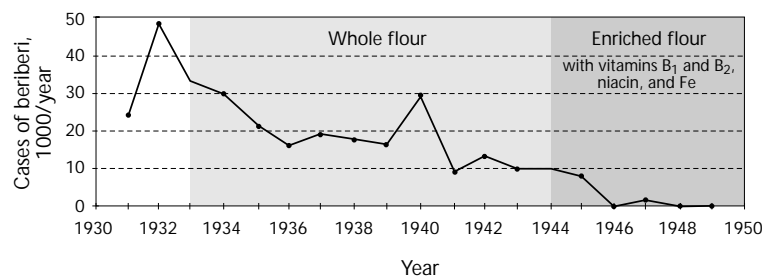


FIG. 1. Effect of enrichment of flour on beriberi in Newfoundland, 1931–49. Source: ref. 8

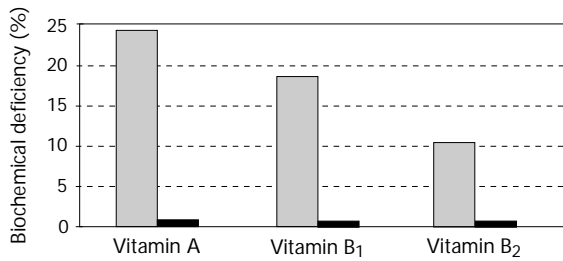


FIG. 2. Biochemical deficiencies of vitamins in Newfoundland before (1944: grey bars) and after (1948: black bars) enrichment of flour. Source: ref. 8

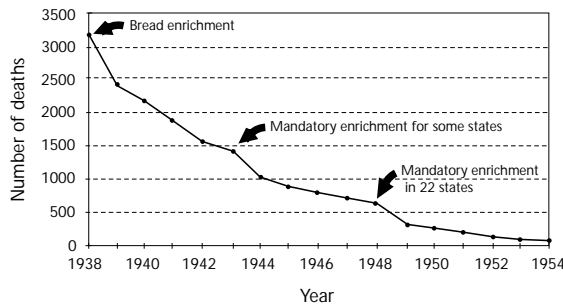


FIG. 3. Effect of enrichment of flour on deaths from pellagra in the United States, 1938–54. Source: ref. 9

dramatically as well (fig. 2).

In the United States during the late 1930s, pellagra caused more than 3,000 deaths annually, mainly in the southern states among a population relying on maize as the main staple food. In 1938, three years before the mandatory introduction of flour enrichment, bakers voluntarily began enriching flour with B vitamins and iron. This measure was associated with a rapid and dramatic decline in pellagra mortality to zero by 1954 (fig. 3).

The introduction of polished rice in the Philippines at the turn of the century led to large outbreaks of beri-

beri. In 1947, in the Province of Bataan, more than 12% of the population was affected by the disease. The distribution of thiamine-fortified rice began on October 1, 1948. This measure was followed by a spectacular reduction in deaths from beri-beri from 254/100,000 to 80 (fig. 4).

Fortification of sugar with vitamin A was initiated in Guatemala in 1974. Sugar was selected because researchers from the Institute of Nutrition of Central America and Panama (INCAP) realized that there was no other staple food reaching all target groups in the country. The prevalence of deficient retinol plasma levels in children (less than 10 µg per 100 ml) was reduced from 3.3% to less than 0.2% within two years (fig. 5).

In 1993 Venezuela started fortifying pre-cooked yellow and white corn flour with vitamins A, B<sub>1</sub>, and B<sub>2</sub>, niacin, and iron. At the same time wheat flour was fortified with vitamins B<sub>1</sub> and B<sub>2</sub>, niacin, and iron. These two cereals were selected as vehicles because they accounted for 45% of the total caloric intake of the population. A survey carried out in Caracas on 397 children showed that the prevalence of iron deficiency (as measured by serum ferritin concentration) and the prevalence of anaemia were reduced from 37% and 19%, respectively, in 1992 to 15% and 10% in 1994 [12].

In 1994 Guatemala revised the fortification of wheat flour, previously fortified with vitamins B<sub>1</sub> and B<sub>2</sub>, niacin, and iron, to include folic acid, on the basis of available information on the high prevalence of deficiency of this vitamin and its function in preventing foetal neural tube defects and some anaemias. This measure was later followed by nearly all Central American countries.

In 1998 the United States will include folic acid in the fortification of wheat flour (1.54 mg/kg flour) in order to prevent the high prevalence of pregnancies affected by spina bifida and other neural tube defects. Most of the newborns affected by this problem die. The US Public Health Service has recommended that women of childbearing age consume at least 400 µg of folic acid daily to prevent neural tube defects [13].

Several technologies are available for fortifying rice. Using the technology of simulated kernels, Dr. H. Flores

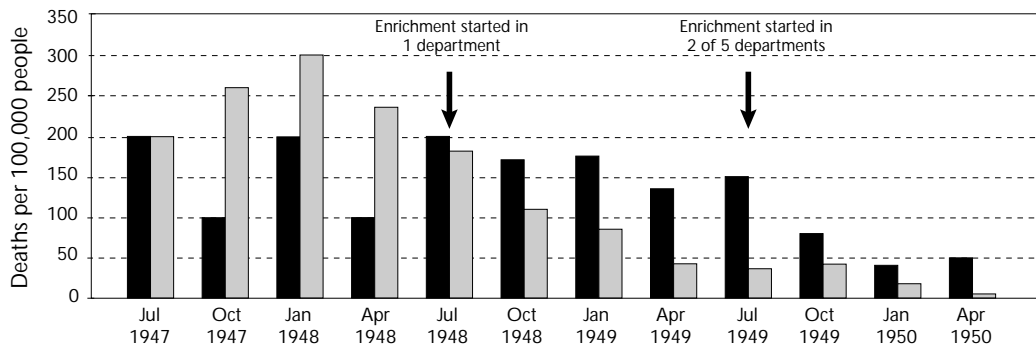


FIG. 4. Effect of enrichment of rice on deaths from beri-beri in Bataan, Philippines, 1947–50. Grey bars: experimental area; black bars: control area. Source: ref. 10

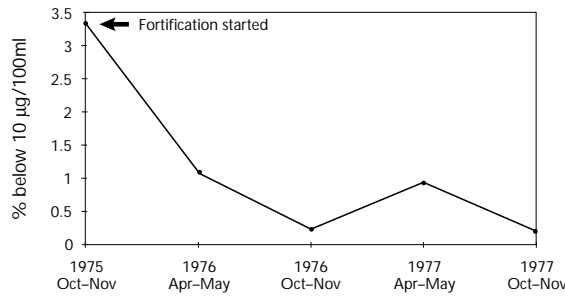


FIG. 5. Effect of enrichment of sugar with vitamin A on plasma levels of retinol in children in Guatemala, 1975–77. Source: ref. 11

demonstrated in Recife, Brazil, that consumption of fortified rice for one month had the same effect as a single dose of 200,000 IU of vitamin A in improving serum retinol levels in children (fig. 6) [14].

Foods supplied to the population as part of complementary feeding programmes can be excellent vehicles for micronutrients. In the Peruvian School Lunch Program, started in 1993, children receive 100 g of biscuits fortified with vitamins B<sub>1</sub> and B<sub>2</sub>, niacin, and iron and a glass of a milk substitute fortified with vitamins A, B<sub>1</sub>, B<sub>2</sub>, B<sub>12</sub> and C niacin, folic acid, iron, zinc, and iodine. In Huancayo, one of the regions covered by the programme, the prevalence of anaemia (haemoglobin less than 13 g/dl, considering altitude) was reduced from 68% to 18% in six months [15].

In 1996 Colombia, Bolivia, and Ecuador started fortification of wheat flour with vitamins B<sub>1</sub> and B<sub>2</sub>, niacin, folic acid, and iron. Fortification of wheat flour with iron and B-complex vitamins and fortification of sugar with vitamin A are being considered by many other countries.

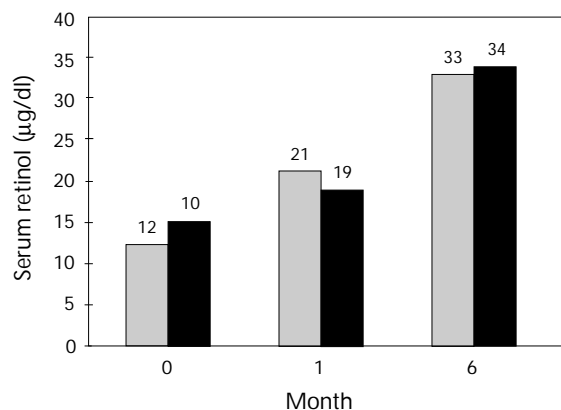


FIG. 6. Effect of fortification of rice with vitamin A (grey bars) in comparison with effect of supplementation with vitamin A (black bars) on serum retinol levels in Brazil. Source: ref. 14

### Fortification with several micronutrients

Because diets are seldom deficient in one micronutrient alone, as shown in table 1, combinations of micronutrients increase the cost-effectiveness of fortification even further by addressing more than one deficiency through the same food.

Furthermore, there are several positive interactions among micronutrients. This is especially true for anaemia, where the role of folate, as well as iron, is well known [16], and there is also enough evidence of the high prevalence of folate deficiency in Latin America, mainly in pregnant women.

Fortification of sugar with vitamin A brought an unexpected finding in Guatemala. As well as reducing the prevalence of vitamin A deficiency, the fortification programme reduced the prevalence of anaemia [17].

A recent study in Indonesia showed that supplementation of pregnant women with iron and vitamin A was significantly more effective in controlling anaemia than supplementation with iron alone (fig. 7).

There is ample evidence that vitamin C plays an important role in improving absorption of non-haem iron. Dr. A. Stekel reported that feeding children for 15 months with milk fortified with 15 mg/L of iron as ferrous sulphate reduced the incidence of anaemia from 36% in the control group to 13% in the fortified group [19]. A more significant reduction was found in children given milk fortified with the same amount of iron and 100 mg of vitamin C per liter, which reduced the prevalence of anaemia from 28% in the control group to 2% in the fortified group (fig. 8).

### Fortification technologies

As shown in table 2, technologies exist for fortifying staple foods [20]. For most foods, the technology is quite simple. The water-soluble vitamins can be dissolved in water and then added to liquid foods such as

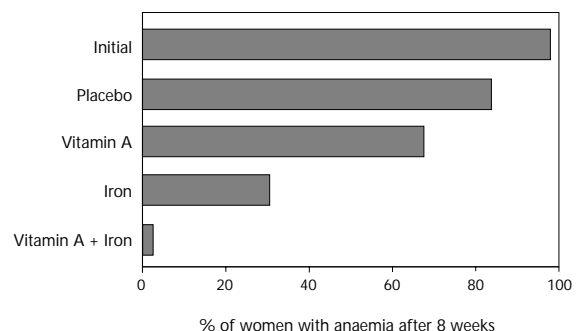


FIG. 7. Effect of supplementation with iron and vitamin A on anaemia in pregnant women in Indonesia. Source: ref. 18

dairy products, fruit juices, and beverages, or they can be mixed in powdered form directly with foods such as wheat flour, corn flour, corn starch, instant powdered beverages, and dry milk. The fat-soluble vitamins can be added directly to foods such as dressing

oils, margarine, mayonnaise, and recombined milk. The industry has been able to microencapsulate the fat-soluble vitamins in order to get them into a water-soluble powdered form and to protect them from oxygen and other components of foods. These powdered forms can be mixed with the water-soluble vitamins and added to foods, as described before.

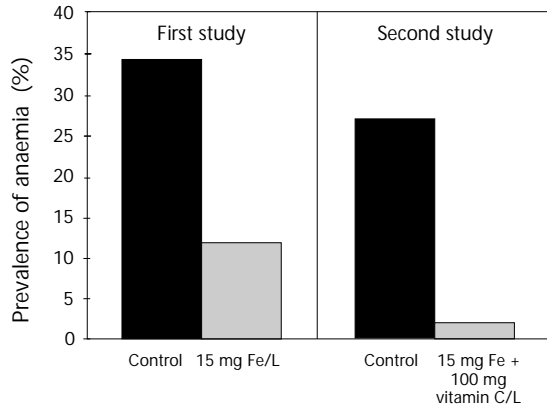


FIG. 8. Effect of enrichment of milk with iron and vitamin C on anaemia in children during the first 15 months of life. Source: ref. 19

Fortification of rice and sugar requires more complex technologies. Vitamin A in powdered form is adhered to the sugar crystals with vegetable oil. Vitamins are sprayed on the rice kernels, which are then coated with appropriate food-grade resins to avoid leaching the vitamins when the rice is washed before cooking. Alternatively, simulated kernels can be produced by technologies similar to the those used for noodles. In this case, the vitamins and minerals in powdered form are mixed with the flour used to produce the simulated kernel.

**Stability**

Vitamins can be affected by oxygen, humidity, heat, acids, redox agents, and light. Furthermore, other components of foods, such as heavy metals, can interfere with the stability of some vitamins. The technology exists

TABLE 2. Staple foods that can be fortified

Food	Vitamins											Minerals	
	β-Carotene	A	D	E	B <sub>1</sub>	B <sub>2</sub>	B <sub>6</sub>	C	Niacin	Folic acid	B <sub>12</sub>	Fe	Ca
Milk													
Liquid	+	+	+	+	+	+	+	+	+	+	+	o	+
Powder	+	+	+	+	+	+	+	+	+	+	+	+	+
With cereal	+	+	+	+	+	+	+	+	+	+	+	+	+
Flour													
Wheat	o	+	+	+	+	+	+	x	+	+	+	+	+
Corn	o	+	+	+	+	+	+	o	+	+	+	+	+
Cassava	o	o	o	o	o	o	o	o	o	o	o	o	o
Rice	o	+	+	+	+	+	+	+	+	+	+	+	+
Rice Snacks	o	+	+	+	+	+	+	+	+	+	+	+	+
Corn flakes	o	+	+	+	+	+	+	+	+	+	+	+	+
Oil	+	+	+	+									
Margarine	+	+	+	+	o	o	o	o	o	o	o	x	o
Mayonnaise	+	+	+	+	o	o	o	o	o	o	o	x	o
Juices	+	o	o	+	+	+	+	+	+	+	+	+	+
Sugar		+											
Powdered beverages	o	+	+	+	+	+	+	+	+	+	+	+	+

Source: ref. 20.

+, Possible; o, trials needed; x, not possible.

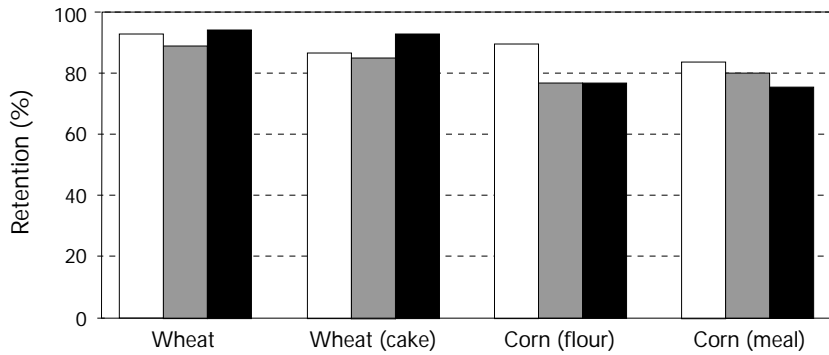


FIG. 9. Stability of 11,000 IU/kg vitamin A added to flours at 27°C after one month (white bars), three months (grey bars), and six months (black bars). Source: ref. 21

to prevent losses, but losses cannot be totally avoided. To ensure that the food contains the declared vitamin levels when it is ingested, the food industry adds extra nutrients to compensate for losses during processing and over the shelf life of the finished product.

Figure 9 shows that vitamin A is very stable when microencapsulated in powdered form and added to different flours, even when the flours are fortified with iron at the same time. When wheat flour is fortified, the typical losses during the production of bread and biscuits are 30% to 40% for vitamin A, 20% to 30% for vitamin B<sub>1</sub>, 15% to 20% for vitamin B<sub>2</sub>, 5% to 10% for niacin, and 15% to 20% for folic acid.

Figure 10 shows the stability of vitamins in pre-cooked corn flour during the production of *arepas* (corn bread), according to results from our laboratories in Switzerland. It is worth mentioning that the flour was also fortified with iron.

### Bioavailability

It is generally recognized that the bioavailability of vitamins added to foods is about the same as for those originally present in foods. Carotenoids and iron, however, require more attention.  $\beta$ -Carotene present in foods is less bioavailable than  $\beta$ -carotene added as a colour or fortificant. The bioavailability of iron depends on several factors. For reduced iron, the most important factor is the mesh size of the form used, the smallest size being the best. Figure 11 shows the relative bioavailability of some typical forms of iron used to fortify foods. As mentioned before, vitamin C significantly improves the bioavailability of non-haem forms of iron.

When selecting the form of iron to be used in the fortification of a food, in addition to its relative bioavailability, the food industry has to consider its cost and potential interactions with the food. Table 3 shows the relative cost of typical forms of iron.

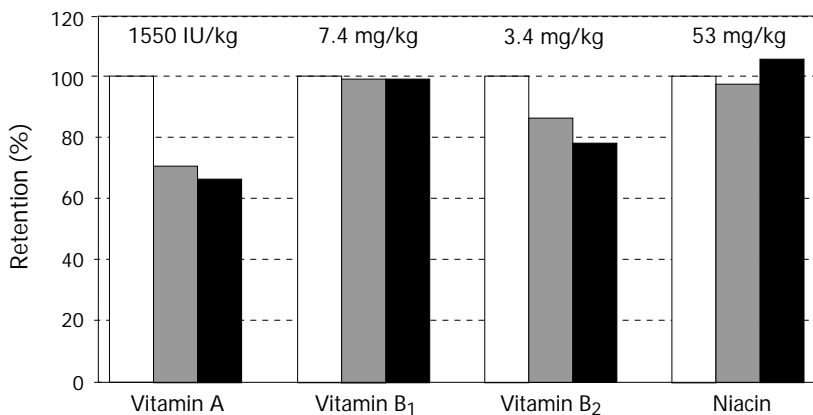


FIG. 10. Stability of vitamins in pre-cooked corn flour (grey bars) and corn bread (*arepas*) (black bars) in Venezuela. White bars, percentage at addition. Source: unpublished data of the authors

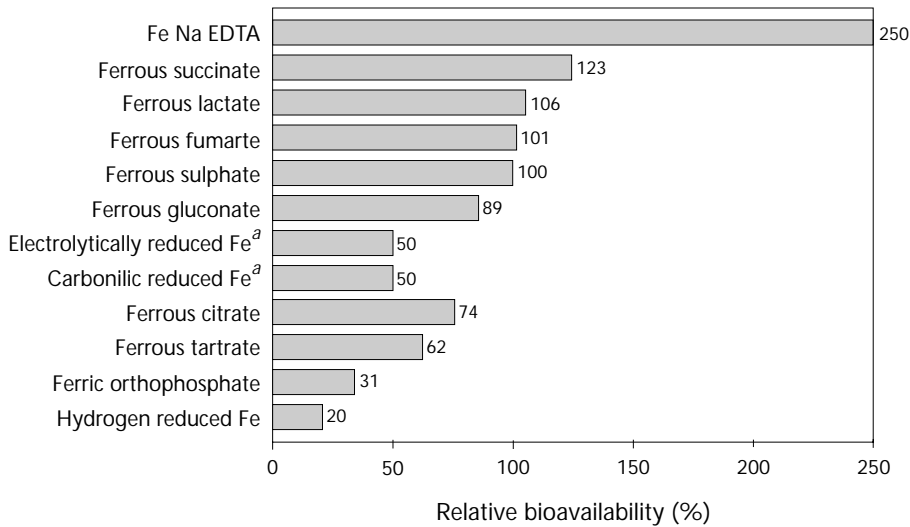


FIG. 11. Relative bioavailability of iron salts. Source: refs. 22–24.

a. Typical values published in several papers.

### $\beta$ -Carotene as colour and vitamin A

$\beta$ -Carotene is extensively used as a food colour, at the same time contributing its nutritional value. As mentioned before, the bioavailability of  $\beta$ -carotene used as a colour is good. Figure 12 shows the nutritional contribution of  $\beta$ -carotene in the doses typically used as a colour for some selected foods.

### Safety

J. N. Hathcok recently published a recompilation of the safety range for vitamins and minerals, defining the NOAEL (Non-Observed Adverse Effect Level) and LOAEL (Lowest Observed Adverse Effect Level) for every micronutrient [25]. Table 4 shows these levels expressed

TABLE 3. Iron content and relative cost of typical forms of iron used to fortify foods

Form of iron	Iron content (%)	Relative cost per unit of iron <sup>a</sup>
Iron reduced with H <sub>2</sub>	98.0	1
Reduced iron, electrolytic	98.0	3
Ferrous sulphate, anhydrous	31.6	2.6
Ferrous fumarate	30.6	3.4
Ferric orthophosphate	26.0	5.9
Ferric lactate	20.5	22.8
Ferrous gluconate	12.5	26.2
FeNa EDTA + 3H <sub>2</sub> O	12.5	50.4

a. Iron reduced with H<sub>2</sub> is the reference substance. Relative cost considers cost and iron content.

as multiples of the RDA [26].

Food fortification is the safest way to deliver necessary amounts of micronutrients to the majority of a population in an effective manner. Fortification levels of the nutritional intervention programmes should be determined by governments on the basis of an evaluation of consumption patterns of the food vehicle and the amount of nutrient needed to prevent deficiency, without possible harm from excessive intake.

### Fortification cost

The direct cost of delivering nutrients as supplements or in food is remarkably low, compared with the social costs of deficiencies. The cost of fortification includes the costs of the fortificant, capital, and labour (for the blending operation), as well as the costs of transport and quality control. Depending on the type of food to be fortified and the fortification level and technology, fortification cost can vary over a wide range. In most cases, according to World Bank figures, it costs less than US\$1 per year to protect an individual against deficiencies of vitamin A, iron, and iodine with food fortification [3]. The cost of fortification to protect an individual for one year against vitamin A deficiency is less than US\$0.30 and against iron deficiency less than US\$0.10. Table 5 shows typical costs of the quantity of micronutrients needed to cover the total requirement during a full year.

Eliminating micronutrient deficiencies can have major yet subtle social and economic benefits. When nutritional deficiencies are eliminated, adverse consequences, such as reduced IQ, impaired growth, reduced work capacity, and death associated with pregnancy and child-

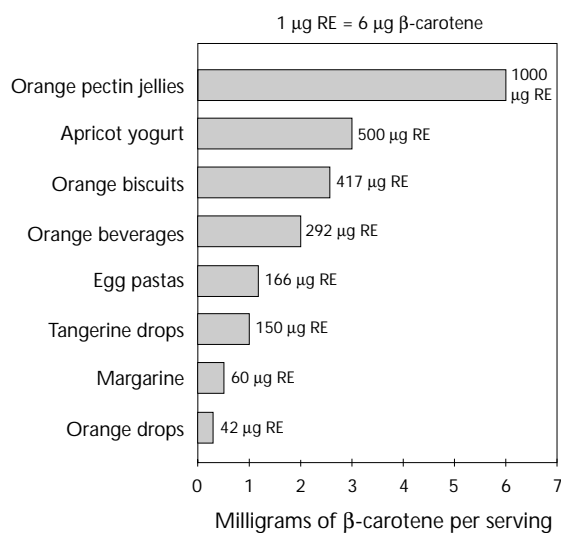


FIG. 12. Nutritional contribution of β-carotene used as food colour

birth are reduced. Food fortification provides maximum benefit for minimum investment.

Food fortification is generally recognized as being the most efficient as well as the most cost-effective means of eliminating micronutrient deficiencies when compared with supplementation and home gardening. In 1994 the USAID published an evaluation of the cost-effectiveness of three vitamin A interventions in Guatemala (fortification, supplementation, and home gardening) and compared the results with similar evaluations performed in Indonesia and the Philippines [27]. When the cost per high-risk person reached was considered, the conclusion was that fortification of staple foods was the cheapest intervention strategy (table 6). Furthermore, fortification was the most sustainable intervention and had the best coverage at the national level.

#### Voluntary versus mandatory fortification

The food industry has responded in some cases by voluntarily fortifying products. However, the development of voluntarily fortified foods has been impaired in some countries because of consumer and, in many cases, government lack of awareness of the prevalence of micronutrient deficiencies and their impact on health. Without consumer demand for fortified products, industry is often not motivated to fortify products voluntarily.

A number of staple foods around the world have been successfully fortified with micronutrients. Tables 7 and 8 show the countries with compulsory fortification of wheat flour and margarine, respectively [28]. As mentioned before, in 1998 the United States will start adding folic acid to wheat flour. In 1997 Ecuador, Bolivia, and Colombia started programmes to fortify wheat flour

TABLE 4. Safety levels of micronutrients

Micronutrient	RDA	No. of times the RDA	
		NOAEL	LOAEL
Vitamin A	3,333 IU	3	6.5
Vitamin D	200 IU	4	10
Vitamin E	15 IU	80	NE
Vitamin K	80 µg	375	NE
Vitamin C	60 mg	> 17	NE
Vitamin B <sub>1</sub>	1.5 mg	33	NE
Vitamin B <sub>2</sub>	1.7 mg	118	NE
Niacin	19 mg	79	158
Vitamin B <sub>6</sub>	2 mg	100	250
Folate	200 µg	5	NE
Vitamin B <sub>12</sub>	2 µg	1,500	NE
Biotin	100 µg	25	NE
Pantothenates	7 mg	143	NE
Ca	800 mg	1.9	> 3.1
P	900 mg	1.9	> 3.1
Mg	350 mg	2	NE
Cu	3 mg	3	NE
I	150 µg	6.7	NE
Fe	10 mg	6.5	10
Se	70 µg	2.9	13
Zn	15 mg	2	4

Source: refs. 25, 26.

RDA, Recommended dietary allowance; NOAEL, non-observed adverse effect level; LOAEL, lowest observed adverse effect level; NE, not established.

TABLE 5. Recommended dietary allowance (RDA) and annual cost of micronutrients per person

Micronutrient	RDA	Annual cost per person (US\$)
Vitamin A	1,000 µg RE	0.253
Vitamin D	400 IU	0.051
Vitamin E	10 mg TE	0.285
Vitamin B <sub>1</sub>	1.5 mg	0.032
Vitamin B <sub>2</sub>	1.7 mg	0.053
Vitamin B <sub>6</sub>	2 mg	0.064
Vitamin C	60 mg	0.558
Niacin	19 mg	0.067
Folate	200 µg	0.016
Vitamin B <sub>12</sub>	3 µg	0.053
Iron	15 mg	0.04
Total		1.47

Source: ref. 26.

with vitamins B<sub>1</sub> and B<sub>2</sub>, niacin, folate, and iron. The United States, Argentina, Venezuela, Mexico, the Philippines, and Malaysia fortify milk with vitamins A and D. Sugar is fortified with vitamin A in Guatemala, Honduras, and El Salvador. In addition to wheat flour, Venezuela has fortified pre-cooked corn flour with vitamins A, B<sub>1</sub> and B<sub>2</sub>, niacin, and iron since 1993.

TABLE 6. Comparison of annual cost-effectiveness estimates between countries

Type of intervention	Annual cost per person (US\$ in 1991)		
	Guatemala 1979 Indonesia 1978 Philippines 1975	Philippines 1980	Guatemala 1991
Fortification			
Per person	0.16	0.14	0.29
Per high-risk person	0.37	0.32	0.65
Capsule distribution			
Per high-risk person	0.48	0.32	1.52
Gardening			
Per person		2.32	1.60
Per high-risk person			3.63

Source: ref. 27.

TABLE 7. Compulsory fortification of wheat flour in different countries (mg/kg)

Country	Vitamin B <sub>1</sub>	Vitamin B <sub>2</sub>	Niacin	Folic acid	Iron
Canada	4.4–7.7	2.7–4.8	35–64	0.4–0.5	29–43
Chile	6.3	1.3	13		30
Costa Rica	4.4–5.5	2.6–3.3	35.2–44		28.7–36.4
Dominican Republic	4.45	2.65	35.62		29.29
El Salvador	4.41	2.65	35.3		28.7
Guatemala	4–6	2.5–3.5	35–40	0.35–0.45	55–65
Honduras	4.4	2.6	35.2		28.7
Nigeria	4.5–5.5	2.7–3.3	35.5–44.4		28.9–36.7
Panama	4.4	2.6	35.2		28.7
Saudi Arabia	> 6.38	> 3.96	> 52.91		> 36.3
United Kingdom	> 2.4		> 16		> 16.5
United States	6.4	4	52.9		44.1
Venezuela	1.5	2	20		20

Source: ref. 28.

## Labelling

Educated consumers can choose foods that enable them to maintain a balanced diet rich in vitamins and minerals. However, governments may need to intervene and require the food industry to provide consumers with the tools they need to make these educated choices.

In the United States, starting in 1975, the Food and Drug Administration (FDA) required most foods to be labeled with their nutritional content. Food labelling is a powerful tool to educate the consumer and to facilitate an informed choice of food. In 1993 the FDA revised the requirements of food labelling to include almost all the foods that consumers purchase. According to the FDA, "The purpose of food label reform is simple: to help consumers choose more healthful diets, and to offer an incentive to food companies to improve the nutritional qualities of their products" [29].

Along with information on saturated fat, cholesterol,

and dietary fibre, the new labelling law mandated that nutrient levels of vitamins A and C, calcium, and iron must be reported on the label. These micronutrients were selected because of public health concerns and are listed on the label in order of priority (vitamin A, vitamin C, iron, and calcium) [29].

The mix of compulsory and voluntary fortification has produced an important increase in the availability of micronutrients in the United States, as shown in [table 9](#).

## Conclusions

More than 2 billion people, one-third of the world's population, suffer from micronutrient deficiencies. Inexpensive and cost-efficient solutions to eradicate these deficiencies are readily available; of these, food fortification is recognized as the most efficient and sustain-

TABLE 8. Compulsory fortification of margarine in different countries (IU/kg)

Country	Vitamin A	Vitamin D
Belgium	22,500–27,000	2,500–3,000
Brazil	15,000–50,000	500–2,000
Canada	> 33,000	> 5,300
Chile	30,000	3,000
Colombia	3,180–7,950	480–1,200
Denmark	25,200	
Ecuador	20,000–30,000	2,000–4,000
El Salvador	15,000	
Guatemala	15,000–50,000	
Honduras	35,000	1,500
India	> 30,000	
Indonesia	25,000–35,000	2,500–3,500
Malaysia	25,000–35,000	2,500–3,500
Mexico	20,000	2,000
Netherlands	> 20,000	> 3,000
Panama	20,000	1,500
Peru	30,000	3,000
Portugal	18,000	
Singapore	> 28,300	> 2,200
Sweden	> 30,000	> 3,000
Taiwan	> 45,000	
Turkey	20,000	1,000
United Kingdom	24,000–30,000	2,800–3,520
United States	33,000	2,080

Source: ref. 28.

able solution. Successful fortification of a staple food reaches everyone, including the poor, pregnant women, young children, and populations that social services can never cover completely. In addition, fortification reaches secondary target risk groups, such as the elderly, the ill, and those who have an unbalanced diet, for whatever reason.

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TABLE 9. Contribution of food enrichment to availability of micronutrients in the United States

Micronutrient	Contribution (%)	
	1970	1985
Vitamin A	10	13
Vitamin C	10	8
Vitamin B <sub>1</sub>	40	24
Vitamin B <sub>2</sub>	15	20
Niacin	20	18
Vitamin B <sub>6</sub>	4	6
Folic acid	0	6
Vitamin B <sub>12</sub>	2	4
Iron	25	24

Source: ref. 30.

Fortification is socially acceptable, requires no change in food habits, does not change the characteristics of the food, can be introduced quickly, has readily visible benefits, can be legally enforced, is relatively easy to monitor, is safe, and is the cheapest intervention for a government. Commitment from government and the food industry, and an educated consumer who demands micronutrient-rich foods, will determine the success of fortification as an intervention strategy.

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